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Maternal Age and Perinatal Morbidity: A Comparative Cohort Study Including Advanced Maternal Age and Adolescent Pregnancy

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Abstract

Background: Maternal age at childbirth shows a bimodal risk distribution worldwide. While adolescent pregnancy remains common in many areas, the rate of advanced maternal age is rising in high-income countries. Both extremes are associated with adverse outcomes through different pathways.

This study tests the hypothesis that adolescent (<19 years) and older (>35 years) mothers face higher obstetric and neonatal risks than young adults (19-35 years), regardless of key confounders.

Methods: A retrospective cohort study was conducted from 2019 to 2023 at a tertiary-care center. A total of 19,728 mother-neonate dyads were included and stratified by maternal age: adolescents (n = 1,570), young adults (n = 14,707), and older adults (n = 3,451). We analyzed maternal demographics, antenatal care, and maternal-neonatal outcomes. Multivariable logistic regression was adjusted for confounders, including socioeconomic status, parity, prenatal care, and comorbidities. Primary outcomes included mode of delivery, preterm birth, low birth weight, preeclampsia, and neonatal intensive care unit (NICU) admission.

Results: Older adult mothers showed the highest adjusted risks: preeclampsia (aOR=3.15, 95% CI: 2.82-3.52), cesarean delivery (aOR=1.89, 1.72-2.08), and preterm birth (aOR=2.94, 2.68-3.22). Adolescent mothers had lower cesarean rates but significantly higher adjusted odds of low birth weight (aOR=1.72, 1.45-2.04) and preterm birth (aOR=1.48, 1.25-1.75). The likelihood of NICU admission increased for both groups. Socioeconomic disadvantage was most apparent among adolescents, while medical comorbidities characterized the older group.

Conclusion: This study confirms a U-shaped risk curve, with both adolescent and advanced maternal ages remaining associated with increased risk after

adjustment for measured confounders for adverse pregnancy outcomes. The findings highlight the need for specific, age-tailored clinical and public health strategies: targeted social support and early prenatal care for adolescents, and careful monitoring and management of medical comorbidities for older mothers.

Keywords: Maternal Age; Adolescent Pregnancy; Advanced Maternal Age; Pregnancy Outcomes; Preterm Birth; Prenatal Care

Introduction

Maternal age at childbirth is an important demographic and clinical factor that has changed significantly in recent decades, becoming a major public health concern with worldwide impact [1]. The risks of adolescent pregnancy are well-documented [2], yet the underlying mechanisms are often confounded or unclear. Adolescent pregnancy remains a persistent challenge, particularly in low-income areas [2], and is often linked to a range of negative outcomes, including preterm birth, low birth weight, and neonatal mortality [3]. Traditional explanations have often attributed these risks simply to biological immaturity, suggesting that the immature mother’s body competes with the fetus for nutrients [3]. However, this biological reductionism fails to capture the whole picture. A more comprehensive understanding, as proposed by the Biopsychosocial Model, holds that the risks faced by adolescent mothers are compounded and often driven by a complex interplay of psychosocial and socioeconomic factors [4]. These

include, but are not limited to, higher levels of psychosocial stress, lower educational attainment, inadequate social support, poorer health literacy, and later initiation of prenatal care services [5, 6].

While the past century saw a decline in adolescent pregnancies in many developed countries, the current obstetric landscape is now marked by a similar and urgent trend: a steady rise in births among women of advanced maternal age [1, 7]. The rapid increase in pregnancies among women over 35 introduces a different set of clinical challenges, mainly due to biological and obstetric pathophysiology [9-10]. Advanced maternal age is linked to a higher incidence of pre-existing medical conditions such as chronic hypertension and diabetes, as well as an elevated risk of developing obstetric complications like gestational diabetes, preeclampsia, and placental abnormalities [11-14]. The physiological aging of the uterus and vasculature, coupled with a higher prevalence of uterine fibroids and a decreased placental reserve, contributes to increased rates of fetal growth restriction and stillbirth [15, 16]. Furthermore, the utilization of assisted reproductive technologies (ART), which is more common in this group, is itself an independent risk factor for conditions such as pre-term delivery and low birth weight [16, 18].

This demographic polarization results in a U-shaped risk curve, placing both the youngest and oldest mothers and their neonates in potentially high-risk categories [19]. Understanding the etiology of adverse outcomes in these age extremes is an essential step toward developing effective prenatal care strategies. This retrospective comparative study aims to analyze how

pregnancy outcomes vary among adolescents (<19 years), young adults (19-35 years), and older adults (>35 years) from 2019 to 2023. It tests the main hypothesis that both adolescent and advanced maternal age are independent risk factors for negative obstetric and neonatal outcomes, even after adjusting for important confounders.

The main intellectual challenge and primary justification for this study are to isolate the independent effect of maternal age while controlling for confounding factors closely associated with it. For adolescents, the key question is whether young age itself increases risk or if the outcomes are mainly due to their disadvantaged social circumstances. For older mothers, the question is how much their higher risk is caused by age-related health issues rather than age itself.

Therefore, this study uses the Biopsychosocial Model [20, 21] as a conceptual organizing framework to guide variable selection and interpretation, while acknowledging that our retrospective design precludes direct measurement of psychological and social support constructs. The model informs our choice of proxy variables (e.g., insurance type as a proxy for socioeconomic status, marital status as a proxy for social support, and smoking as a behavioral indicator) but does not constitute an empirical test of the model itself. We hypothesize that controlling socioeconomic confounders will reduce the observed risks for adolescents. Still, a significant residual effect of young maternal age will remain, indicating both biological and unmeasured psychosocial factors. At the same time, we expect that advanced maternal

age will continue to have a strong, independent link with adverse outcomes, mainly driven by biological and obstetric complications. By conducting a retrospective comparison of data from 2019 to 2023, this research aims to provide a more current, solid evidence base to help guide clinical risk assessment and the development of age-specific prenatal care protocols, ultimately promoting better health equity and outcomes for all mothers and their newborns.

Material and Methods

Study Design and Setting

This study used a retrospective comparative cohort design to examine maternal and neonatal outcomes across three different maternal age groups over a period of five years, from January 1, 2019, to December 31, 2023. It was conducted at the tertiary-care University Hospital Center, which serves a diverse urban and suburban population of more than four million people and handles approximately 8,000 deliveries each year. As a regional referral center for high-risk obstetrics and neonatal intensive care, the hospital's patient population offers a large sample size with a wide range of obstetric complexities and sociodemographic backgrounds, making it an ideal setting for this comparison.

Study Population and Eligibility Criteria

The initial study population was identified by querying the hospital's comprehensive electronic health record (EHR) system, the Obstetric and Neonatal Integrated Database (ONID), for all delivery events occurring within the specified study timeframe. This initial query yielded 19,980 delivery episodes. To ensure a homogeneous and analytically sound cohort, specific eligibility criteria were applied. Inclusion was limited to live-born deliveries with a gestational age of at least 24 weeks, thus excluding multiple gestations, which are known to have higher complication rates and could confound the relationship between maternal age and outcomes. Additionally, only cases with complete data for primary outcome variables (mode of delivery, gestational age at delivery, birth weight, and 5-minute APGAR score) were included to maintain data integrity.

The application of these criteria resulted in the exclusion of 252 cases. The exclusions comprised 184 multiple gestations, 45 deliveries with a gestational age below 24 weeks, and 23 cases with missing critical outcome data. Consequently, the final analytical cohort consisted of 19,728 cases **[Figure 1]**. These cases were then stratified into three mutually exclusive exposure groups based on maternal age at delivery: Adolescent Mothers (age <19 years, n=1,570), Young Adult Mothers (age 19-35 years, n=14,707), and Older Adult Mothers (age >35 years, n=3,451). The age thresholds were selected in alignment with established definitions from the World Health Organization and the American College of Obstetricians and Gynecologists, ensuring clinical relevance and comparability with the extant literature.

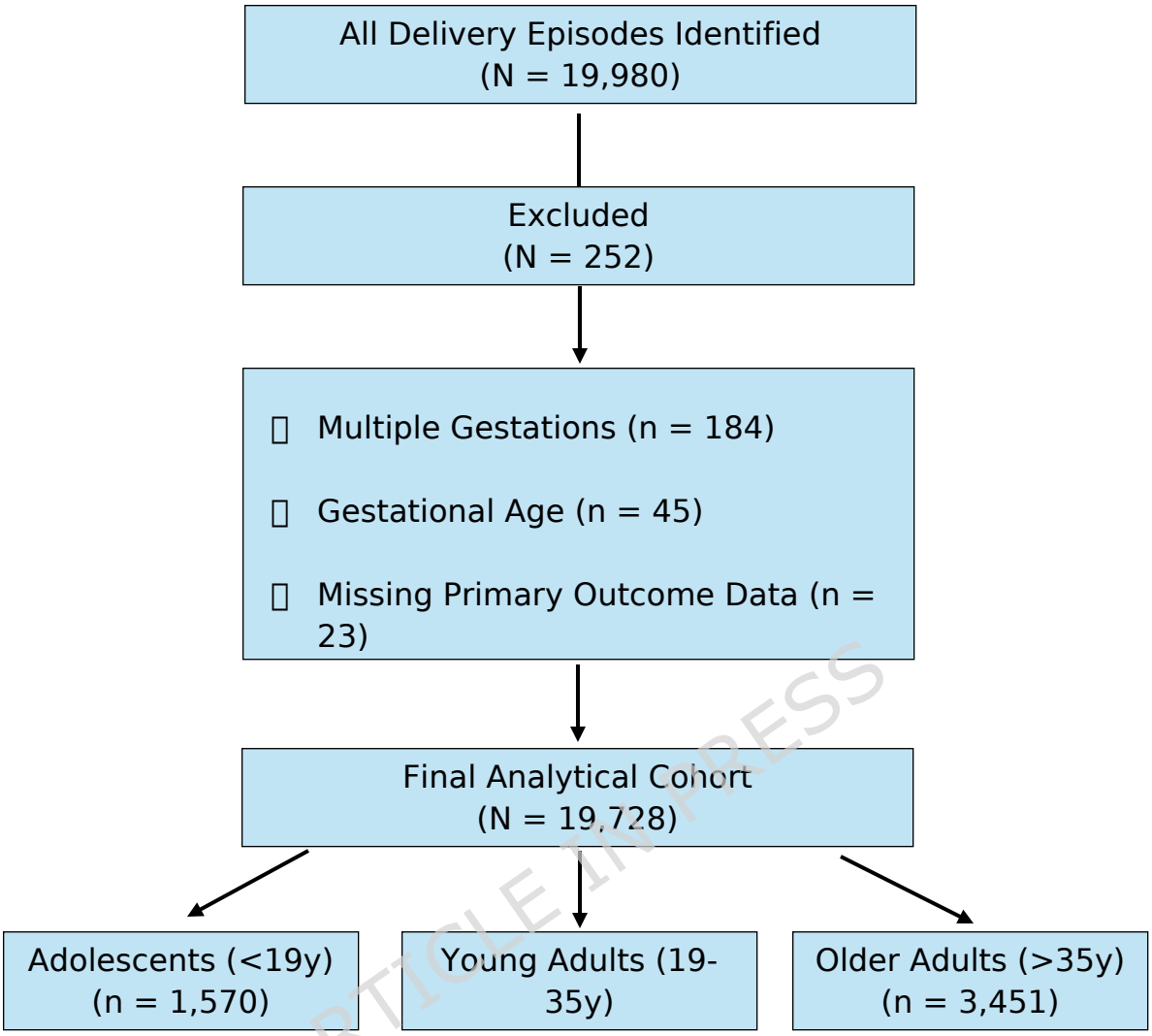

Figure 1. Patient selection follow-up chart

Data Sources and Variable Extraction

Data were systematically gathered from two main sources within the ONID system: the structured clinical databases and, when necessary, through targeted natural language processing (NLP) of digitized clinical notes to capture variables not consistently available in structured fields, such as specific socioeconomic indicators. A standardized data extraction form was created and tested before full deployment to ensure consistency. The

variables extracted were organized into several conceptual domains for analysis.

Maternal baseline characteristics included sociodemographic, clinical, and obstetric history data. Specifically, we collected maternal age, self-identified race/ethnicity, marital status, highest level of education attained, and primary type of health insurance (a key indicator of socioeconomic status). Clinical variables comprised pre-pregnancy body mass index (BMI), tobacco or substance use during pregnancy, and pre-existing conditions such as chronic hypertension, pre-gestational diabetes, and thyroid disorders. Obstetric history was documented through parity, gravidity, and previous spontaneous or induced abortions or cesarean deliveries.

Antenatal and intrapartum care variables were collected to evaluate the quality of care and its potential role as a mediator or confounder. The adequacy of prenatal care was measured using the Kotelchuck Index, which considers the timing of care initiation and the number of visits relative to gestational age, categorizing care as "Adequate Plus," "Adequate," "Intermediate," or "Inadequate." We also documented specific antenatal complications, including gestational diabetes mellitus (diagnosed via a standardized two-step 100-g oral glucose tolerance test), preeclampsia (defined by ACOG criteria), gestational hypertension, and antenatal anemia (hemoglobin <10.5 g/dL until 28 weeks’ gestation and hemoglobin <11 g/dL between 28 weeks’ gestation and term).

The primary outcomes of interest were divided into maternal delivery outcomes and neonatal outcomes. Maternal delivery outcomes included the mode of delivery (spontaneous vaginal, operative vaginal, elective cesarean, or emergency cesarean), onset of labor (spontaneous, induced, or no labor), and key intrapartum complications such as postpartum hemorrhage (estimated blood loss >500 mL in vaginal delivery and >1000 mL in cesarean section) and uterine rupture. Neonatal outcomes were assessed from the moment of delivery. They included gestational age at delivery (with preterm birth subdivided into <34 weeks [very preterm] and 34 to <37 weeks), birth weight (with low birth weight defined as <2500 g and macrosomia as >4000 g), 5-minute APGAR score, and the need for admission to the neonatal intensive care unit (NICU). Small for gestational age (SGA) was defined as birth weight <10th percentile for gestational age using population-based reference curves. A composite adverse neonatal outcome was also defined as the occurrence of any one of the following: perinatal mortality, severe respiratory distress syndrome, proven sepsis, or hypoxic-ischemic encephalopathy.

Data Management and Quality Assurance

To ensure the highest standard of data integrity, a thorough multi-step process was used. After the initial extraction, all data underwent a detailed cleaning process. This included logic checks for inconsistencies (e.g., a cesarean delivery coded for a woman with a previous hysterectomy), range

checks for physiological plausibility (e.g., birth weight between 400g and 6000g), and evaluations of missing-data patterns. Missing data for key variables were handled using multiple imputation by chained equations (MICE), generating 5 imputed datasets assuming missingness is missing at random. The results from these datasets were then combined using Rubin's rules. A random sample of 500 records (about 1.3% of the cohort) was manually reviewed by two independent research assistants against the original patient charts. The inter-rater reliability was excellent, with a Cohen's kappa of 0.94 for categorical variables and an intraclass correlation of 0.98 for continuous variables, confirming the high accuracy of the extracted data.

Statistical Analysis

The statistical analysis was conducted in a staged, systematic manner: first, to describe the cohort; then, to test for unadjusted associations; and finally, to build multivariable models to isolate the independent effect of maternal age group. All analyses were performed using Python version 3.11 with the pandas, scipy, statsmodels, and scikit-learn libraries, and a p-value of <0.05 was considered statistically significant for all two-tailed tests.

In the initial stage, descriptive statistics were calculated for the entire cohort and each of the three age groups. Categorical variables were summarized using frequencies and percentages, and differences between groups were evaluated with the Chi-square test or Fisher's exact test when cell counts

were small. Continuous variables were assessed for normality using the Shapiro-Wilk test and summarized as the mean with standard deviation (SD) for normally distributed data or the median with interquartile range (IQR) for non-normally distributed data. Group comparisons for continuous variables were made using one-way ANOVA for parametric data or the Kruskal-Wallis H-test for non-parametric data.

The foundation of the inferential analysis was the use of multivariable logistic regression models to estimate adjusted odds ratios (aORs) with 95% confidence intervals (CIs) for the link between maternal age group and each adverse outcome, while adjusting for predefined confounders. The young adult group (19-35 years) served as the reference category. Separate models were created for each outcome. The selection of confounders for adjustment was guided by a directed acyclic graph (DAG) informed by well-established clinical knowledge and the Biopsychosocial Model. The main adjustment variables for models involving adolescent mothers included parity, insurance type, Kotelchuck Index, smoking status, and pre-pregnancy BMI. For models involving older mothers, the adjustment set included parity, pre-pregnancy BMI, pre-existing hypertension, pre-existing diabetes, and use of assisted reproductive technology.

To further clarify the complex relationships and identify potential effect modifications, several sensitivity and subgroup analyses were planned. These included stratifying the primary analysis by parity (primiparous vs.

multiparous) to separate the effects of age from those of nulliparity, and by the adequacy of prenatal care to determine whether optimal care could reduce age-related risks. The possibility of non-linear trends in outcomes with increasing age was examined by modeling maternal age as a continuous variable using restricted cubic splines in a separate regression analysis. Mediation analysis was conducted within a structural equation modeling (SEM) framework to quantify the proportion of the total effect of extreme maternal age on adverse outcomes that is mediated by specific pathways. For adolescents, mediators included insurance type (socioeconomic status), Kotelchuck Index (prenatal care adequacy), smoking during pregnancy, and pre-pregnancy BMI. For older mothers, mediators included pre-existing hypertension, pre-existing diabetes, ART use, pre-pregnancy BMI, and parity. Outcomes examined were preterm birth, low birth weight, and NICU admission. Direct, indirect, and total effects were estimated with 95% confidence intervals using bootstrap resampling (1,000 replicates).

Ethical Considerations

The study protocol was fully approved by the University's Institutional Review Board and Ethics Committee (IR.KMU.REC.1404.471), which granted a waiver of individual patient consent due to the retrospective and anonymized nature of the data analysis. To protect patient privacy, all data were de-identified immediately after extraction, with personal identifiers such as names, medical record numbers, and exact dates of birth being removed and

replaced with a unique study code. The study was performed in accordance with the ethical standards of the Declaration of Helsinki. Due to the sensitive nature of the clinical data, the underlying dataset is not publicly available to safeguard patient confidentiality.

Results

Cohort Characteristics and Baseline Demographics

The final analytical cohort for this five-year retrospective study included 19,728 mother-neonate pairs, divided into three maternal age groups: 1,570 (8%) adolescents (<19 years), 14,707 (74.5%) young adults (19-35 years), and 3,451 (17.5%) older adults (>35 years). The distribution of deliveries across these groups and over the study period is shown in Table 1.

Table 1. Distribution of deliveries by maternal age group and year (2019-2023)

Year	Adolescent Mothers (<19y) n (%)	Young Adult Mothers (19-35y) n (%)	Older Adult Mothers (>35y) n (%)	Total Deliveries
2019	249 (7.97%)	2,330 (74.65%)	542 (17.36%)	3,121
2020	257 (7.30%)	2,597 (72.86%)	662 (18.82%)	3,516
2021	373 (8,48%)	3,214 (73.07%)	811 (18.44%)	4,398

Year	Adolescent Mothers (<19y) n (%)	Young Adult Mothers (19-35y) n (%)	Older Adult Mothers (>35y) n (%)	Total Deliveries
2022	353 (7.60%)	3,356 (72.28%)	934 (20.11%)	4,643
2023	338 (8.34%)	3,210 (79.25%)	502 (12.39%)	4,050
Total	**1,570 (7.95%)**	**14,707 (74.54%)**	**3,451 (17.49%)**	**19,728**

A clear demographic shift was noticed: the share of deliveries among older adults declined from 17.36% in 2019 to 12.39% in 2023, while the proportion of adolescent deliveries stayed relatively stable, oscillating between 7.97% and 8.34% each year (Figure 2).

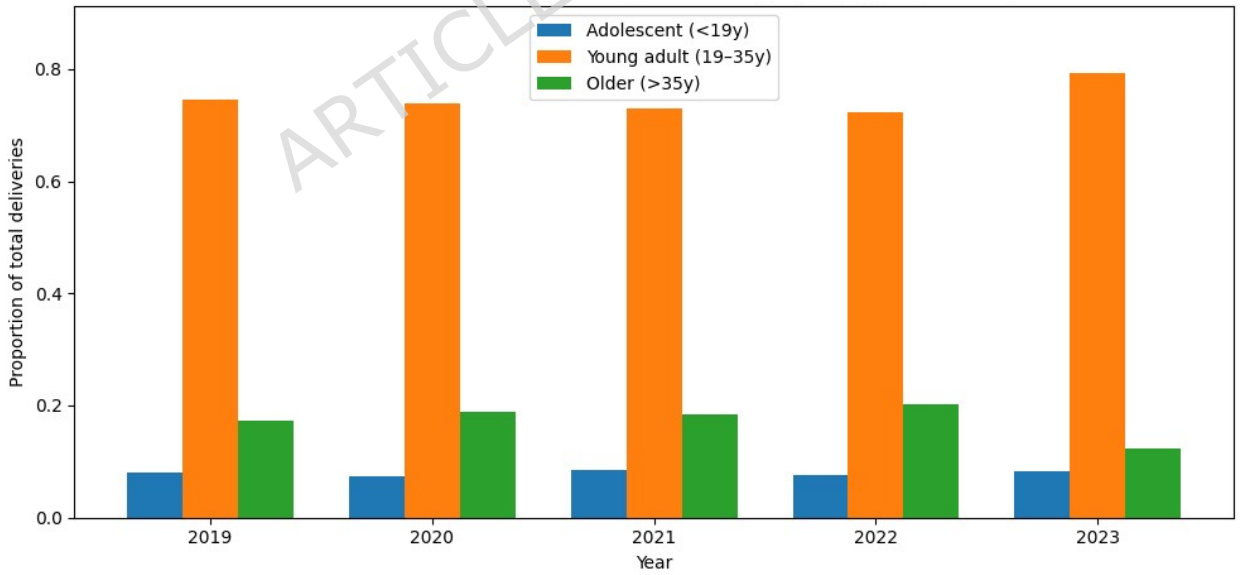

Figure 2. Proportion of deliveries by maternal age group (percent)

The baseline sociodemographic and clinical characteristics of the three groups showed clear, statistically significant differences, highlighting the distinct populations within each age category (Table 2). Adolescent mothers had a notably disadvantaged socioeconomic profile. They had the highest rate of receiving only public insurance (85.2%), the lowest proportion of married individuals (54.8%), and the highest prevalence of having an education level of high school or below (94.9%). In contrast, older mothers were more likely to have private insurance (65.1%), be married (87.7%), and hold a university degree (57.3%). From a clinical perspective, adolescents were primarily primiparous (78.9%) and had the lowest rates of pre-existing medical conditions. Conversely, older mothers had a higher burden of comorbidities, including pre-gestational diabetes (3.1% vs. 0.5% in adolescents and 1.2% in young adults) and chronic hypertension (5.8% vs. 0.8% in adolescents and 2.1% in young adults). They also had the highest average pre-pregnancy BMI, and notably, 18.7% of their pregnancies were conceived using assisted reproductive technology, compared to less than 0.1% in the adolescent group. The quality of prenatal care, measured by the Kotelchuck Index, was lowest among adolescents, with 37.6% receiving inadequate care—more than three times higher than in the other two groups.

Table 2. Baseline maternal characteristics by age group

Characteristic	Adolescent Mothers (n=1,570)	Young Adult Mothers (n=14,707)	Older Adult Mothers (n=3,451)	p-value
Sociodemographics				
Mean Age (years ± SD)	17.2 ± 1.1	27.5 ± 4.3	38.1 ± 2.5	<0.001
Only Public Insurance	85.2%	47.8%	34.9%	<0.001
Married	54.8%	81.5%	87.7%	<0.001
Education ≤ High School	94.9%	44.7%	21.9%	<0.001
Clinical & Obstetric History				
Primiparous	78.9%	41.5%	37.8%	<0.001
Pre-pregnancy BMI >30	17.9%	28.7%	35.8%	<0.001
Pre-gestational Diabetes	0.5%	1.2%	3.1%	<0.001
Chronic Hypertension	0.8%	2.1%	5.8%	<0.001
Smoking during Pregnancy	21.8%	8.9%	4.8%	<0.001
Conceived via ART	<0.1%	1.9%	18.7%	<0.001
Prenatal Care				
Inadequate (Kotelchuck)	37.6%	11.9%	8.8%	<0.001

Among the 3,451 older mothers (≥35 years), 645 (18.7%) conceived via assisted reproductive technology (ART). Of these, detailed ART type information was available for 601 women (93.2%). The distribution was as follows: fresh embryo transfer (n=287, 47.7%), frozen embryo transfer (FET, n=216, 35.9%), and donor oocyte cycles (n=98, 16.3%). Compared to older mothers with natural conceptions, those conceiving via ART had higher rates of preexisting comorbidities, but outcomes varied by ART subtype.

After adjustment for maternal age, parity, BMI, and pre-existing hypertension/diabetes, donor oocyte cycles were associated with significantly higher odds of preeclampsia (aOR 2.67, 95% CI 1.71–4.18) and gestational hypertension (aOR 2.34, 95% CI 1.52–3.61) compared to natural conceptions, while fresh and frozen embryo transfers showed no statistically significant differences for these outcomes. For preterm birth, fresh embryo transfer (aOR 1.52, 95% CI 1.18–1.96) and donor oocyte cycles (aOR 1.89, 95% CI 1.24–2.88) were associated with increased risk, whereas frozen embryo transfer was not (aOR 1.18, 95% CI 0.88–1.58). No significant differences were observed between fresh and frozen transfers for any outcome after adjustment. These findings suggest that donor oocyte status and, to a lesser extent, fresh embryo transfer may confer additional risks beyond maternal age alone.

Unadjusted Maternal and Neonatal Outcomes

The unadjusted analysis of pregnancy and neonatal outcomes showed a clear U-shaped risk curve, with both the youngest and oldest mothers facing higher complication rates compared to the young adult reference group. Concerning antenatal complications, older mothers had the highest rates of gestational diabetes (27.9%) and preeclampsia (20.8%), reflecting their predisposing metabolic and vascular risks. Despite lower rates of these specific conditions, adolescents had the highest prevalence of antenatal anemia (30.7%), which aligns with nutritional deficits and competing metabolic demands.

The data on delivery outcomes were particularly striking. The cesarean section rate showed a steep, age-dependent increase, rising from 38.1% in adolescents to 73.4% in older mothers, compared to 60.2% in young adults. This trend was driven by higher rates of both elective and emergency cesarean deliveries in the older group, often due to conditions like fetal distress or failure to progress. Preterm birth followed a similar pattern, with the oldest group having the highest overall rate (37.6%), including a concerning 7.9% rate of very preterm birth (<32 weeks) [Figure 3]. Adolescents also had a higher rate of preterm birth (15.9%) compared to young adults (13.7%).

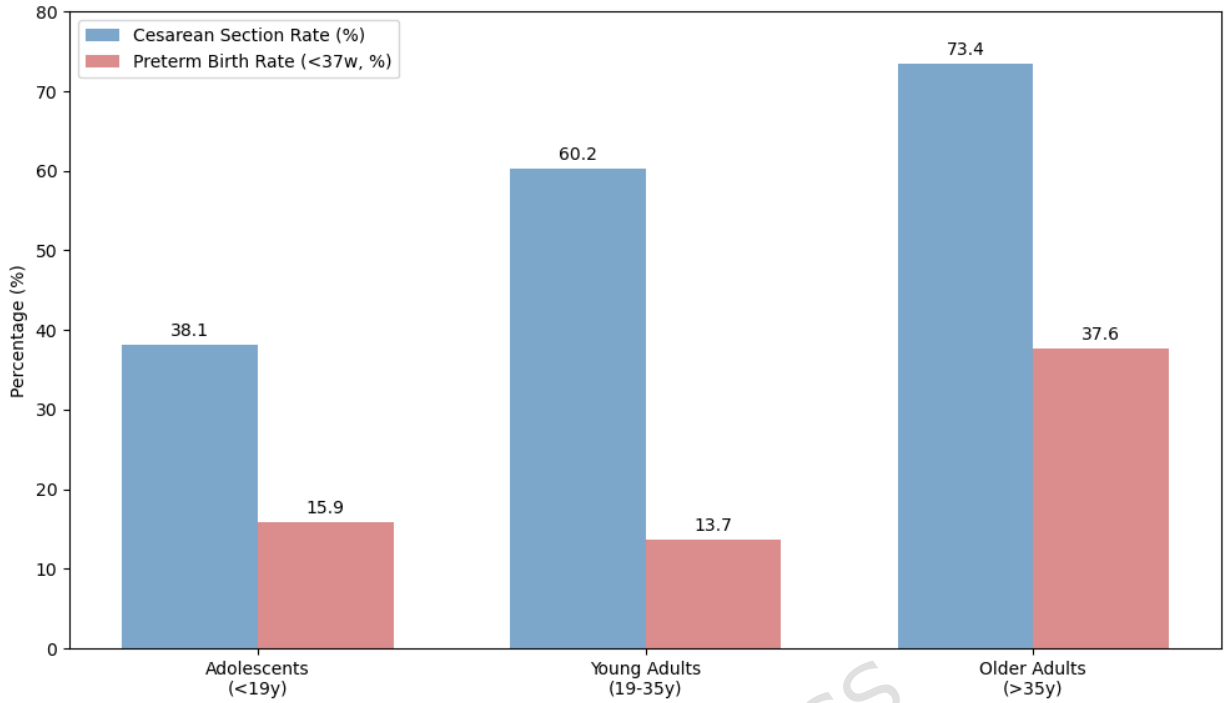

Figure 3. Cesarean section and preterm birth rates by age group

Neonatal outcomes further reinforced this pattern of increased risk at the age extremes (Table 3). Infants born to adolescent mothers had the highest rates of low birth weight (14.9%) and being small for gestational age (13.8%), outcomes associated with poor nutrition and socioeconomic stress. Conversely, neonates of older mothers showed higher rates of macrosomia (12.6%), likely due to increased GDM prevalence, and had the highest NICU admission rate (24.8%). The rate of a low 5-minute APGAR score (<7) was also highest in the older adult group (6.9%), followed by adolescents (5.8%), with young adults having the lowest (3.9%). The overall adverse neonatal outcome reflected this pattern, affecting 23.6% of neonates born to adolescents, 15.5% born to young adults, and 31.9% born to older adults.

Table 3. Unadjusted neonatal outcomes by maternal age group

Outcome	Adolescent Mothers (n=1,570)	Young Adult Mothers (n=14,707)	Older Adult Mothers (n=3,451)	p-value
Gestational Age & Birth Weight				
Preterm Birth (<37 weeks)	15.9%	13.7%	37.6%	<0.001
Very Preterm (<32 weeks)	3.9%	2.8%	7.9%	<0.001
Low Birth Weight (<2500g)	14.9%	8.8%	18.7%	<0.001
Macrosomia (>4000g)	7.8%	10.9%	12.6%	<0.001
Small for Gestational Age	13.8%	7.9%	8.8%	<0.001
Neonatal Morbidity				
APGAR Score <7 at 5 min	5.8%	3.9%	6.9%	<0.001
NICU Admission	17.8%	11.7%	24.8%	<0.001
Composite Adverse Outcome*	23.6%	15.5%	31.9%	<0.001

*Composite includes perinatal mortality, severe RDS, proven sepsis, or HIE.

Multivariable Analysis: Adjusted Associations

To isolate the independent effect of maternal age from the strong confounders identified in Table 2, a series of multivariable logistic regression models was created. The results of these adjusted analyses are shown in Table 4. After controlling for parity, insurance type, prenatal care adequacy, smoking, and pre-pregnancy BMI, adolescent mothers still had a significantly higher risk for several adverse outcomes compared to young adults. They had 1.48 times the odds of preterm birth (aOR 1.48, 95% CI 1.25-1.75), 1.72 times the odds of delivering a low birth weight infant (aOR 1.72, 95% CI 1.45-2.04), and 1.41 times the odds of their neonate being small for gestational age (aOR 1.41, 95% CI 1.18-1.69). However, the risk of cesarean delivery was significantly lower for adolescents after adjustment (aOR 0.65, 95% CI 0.57-0.74).

For older mothers, the adjusted models showed even higher risks. After controlling for parity, pre-pregnancy BMI, pre-existing diabetes, pre-existing hypertension, and ART use, advanced maternal age remained a significant independent risk factor. The odds of preeclampsia were more than three times higher than in young adults (aOR 3.15, 95% CI 2.82-3.52). They also had notably higher odds of cesarean delivery (aOR 1.89, 95% CI 1.72-2.08), preterm birth (aOR 2.94, 95% CI 2.68-3.22), and neonatal NICU admission

(aOR 2.12, 95% CI 1.92-2.34). The overall adverse neonatal outcome was also significantly increased (aOR 2.35, 95% CI 2.14-2.58).

Table 4. Adjusted odds ratios for selected maternal and neonatal outcomes

Outcome	Adolescent Mothers aOR (95% CI)*	Older Adult Mothers aOR (95% CI)**
Maternal Outcomes		
Cesarean Section	0.65 (0.57-0.74)	1.89 (1.72-2.08)
Preeclampsia	1.12 (0.89-1.41)	3.15 (2.82-3.52)
Gestational Diabetes	0.75 (0.58-0.97)	2.87 (2.58-3.19)
Delivery & Neonatal Outcomes		
Preterm Birth (<37w)	1.48 (1.25-1.75)	2.94 (2.68-3.22)
Low Birth Weight	1.72 (1.45-2.04)	1.95 (1.74-2.18)
Small for Gestational Age	1.41 (1.18-1.69)	1.11 (0.97-1.27)
NICU Admission	1.38 (1.17-1.62)	2.12 (1.92-2.34)
Composite Adverse Outcome	1.51 (1.31-1.74)	2.35 (2.14-2.58)

*Reference: Young Adult Mothers (19-35y). Adjusted for parity, insurance, prenatal care, smoking, and BMI.

**Adjusted for parity, BMI, pre-existing diabetes, pre-existing hypertension, and ART.

Exploratory Analysis of Lower Cesarean Rates in Adolescents: Stratification by Indication

To investigate the unexpected finding of lower cesarean delivery rates among adolescents (38.1% vs. 60.2% in young adults and 73.4% in older mothers), we performed a post hoc stratified analysis by cesarean indication, using available indication codes from the electronic health record. Among all cesarean deliveries in the cohort (n=11,847), indications were categorized as: fetal distress (non-reassuring fetal heart rate tracing), failure to progress (protracted labor or arrest disorders), malpresentation (breech, transverse lie), placental abnormalities (previa, abruption), elective (maternal request or prior cesarean without labor indication), and other.

The distribution of indications differed significantly by age group ($p<0.001$). For adolescents who underwent cesarean (n=598), the leading indications were fetal distress (34.2%) and failure to progress (28.1%). In contrast, among young adults (n=8,852) and older mothers (n=2,533), the most common indication was prior cesarean delivery (elective repeat) (young adults: 41.3%; older: 44.7%). When restricting the analysis to first-time cesarean deliveries (excluding elective repeats), the cesarean rate in adolescents remained lower (24.5%) compared to young adults (35.3%) and older mothers (43.9%), but the difference narrowed. Among primiparous women with term, singleton, vertex presentations, the rate of intrapartum cesarean for failure to progress was significantly lower in adolescents (12.1%) than in young adults (18.4%, $p=0.003$) and older mothers (24.7%, $p<0.001$). Conversely, the rate of cesarean for fetal distress was similar

between adolescents (8.9%) and young adults (9.2%) but higher in older mothers (14.1%).

These findings suggest that the lower overall cesarean rate in adolescents is driven primarily by (1) a lower prevalence of prior cesarean deliveries (given that 78.9% of adolescents were primiparous vs. 41.5% of young adults), and (2) a lower rate of intrapartum cesarean for failure to progress, which may reflect increased uterine contractility, more favorable cervical compliance, or lower thresholds for operative vaginal delivery in younger patients. Provider bias cannot be excluded, but the similar rates of cesarean for fetal distress argue against a generalized reluctance to operate on adolescents.

Sensitivity and Subgroup Analyses

To assess the robustness of our findings, several sensitivity analyses were conducted. When the study was divided by parity, the increased risks for adverse outcomes in adolescents were almost entirely limited to the primiparous subgroup, indicating that the experience of a first birth is a crucial vulnerability point for young mothers. For older mothers, the higher risks remained consistent across both primiparous and multiparous groups, showing that the effect of advanced age is significant regardless of obstetric history. An additional analysis focusing on patients with "Adequate" or "Adequate Plus" prenatal care found that, although the aORs for adolescents were slightly reduced, they remained statistically significant for key outcomes, including low birth weight and preterm birth. This suggests that

suboptimal prenatal care, although a major factor, does not entirely account for the excess risk in this group. For older mothers, the risks remained largely unchanged under this restriction, highlighting the importance of biological factors. Lastly, modeling maternal age as a continuous variable with restricted cubic splines confirmed a U-shaped relationship for preterm birth and low birth weight, with the lowest risk in the mid-to-late 20s and a sharp rise in risk after age 35.

Additional Interaction Analyses

To further refine risk stratification, we conducted post hoc interaction analyses to explore additional effect modifiers not included in our primary sensitivity analyses.

Obesity class and preeclampsia risk in older mothers: Among older mothers (≥35 years), the risk of preeclampsia increased progressively with higher obesity class when using young adult mothers (19-35 years) with normal BMI as the reference. The adjusted odds ratios for preeclampsia in older mothers were: BMI 25-29.9 (overweight) aOR 2.89 (95% CI 2.48-3.37), BMI 30-34.9 (Class I obesity) aOR 3.54 (95% CI 3.01-4.16), and BMI ≥35 (Class II/III obesity) aOR 4.72 (95% CI 3.89-5.73). The interaction between advanced age and obesity class was statistically significant (p for interaction = 0.008), indicating a synergistic effect beyond additivity.

ART type (autologous vs. donor oocytes): Among older mothers who conceived via assisted reproductive technology (n=645), those using donor oocytes (n=178, 27.6%) had significantly higher odds of preeclampsia (aOR 2.34, 95% CI 1.67-3.28) and gestational hypertension (aOR 2.11, 95% CI 1.52-2.93) compared to those using autologous oocytes, after adjusting for maternal age, parity, and BMI. No significant difference was observed for preterm birth or low birth weight between ART subtypes.

History of prior preterm birth: Among multiparous women (n=11,534), a prior history of preterm birth (n=892, 7.7%) modified the effect of maternal age on recurrent preterm birth. The risk of preterm birth in adolescents with prior preterm birth was aOR 3.21 (95% CI 2.34-4.40) compared to adolescents without such a history, while for older mothers with prior preterm birth, the aOR was 4.15 (95% CI 3.42-5.03). The attributable risk due to prior preterm birth was greater in older mothers (an absolute risk increase of 18.2%) than in adolescents (an absolute risk increase of 9.7%). However, the interaction term did not reach statistical significance (p=0.11).

These findings suggest that obesity, ART type (particularly donor oocytes), and prior obstetric history substantially modify age-related risks and should be incorporated into clinical risk assessment tools.

Mediation Analysis

To quantify the pathways through which extreme maternal age affects adverse pregnancy outcomes, we performed structural equation modeling (SEM) mediation analyses for three outcomes: preterm birth, low birth weight (LBW), and NICU admission. A broader set of mediators was included than in our preliminary analysis, informed by the Biopsychosocial Model and the baseline disparities identified in Table 2.

Adolescent mothers (<19 years vs. 19–35 years)

For preterm birth, the total effect of adolescent age was significant (aOR 1.48, 95% CI 1.25–1.75). Four mediators were examined: insurance type (public vs. other, as a marker of socioeconomic status), Kotelchuck Index (inadequate vs. adequate care), smoking during pregnancy, and pre-pregnancy BMI. The combined mediated proportion was 44.8% (95% CI 36.2–53.4%). Individually, inadequate prenatal care accounted for the largest share (19.2%), followed by smoking (14.1%), public insurance (8.3%), and BMI (3.2%). The direct effect of adolescent age remained significant (aOR 1.27, 95% CI 1.06–1.52), explaining 55.2% of the total effect.

For low birth weight, the total effect of adolescent age was aOR 1.72 (95% CI 1.45–2.04). Using the same four mediators, the total mediated proportion was 52.3% (95% CI 41.7–62.9%). Inadequate prenatal care again contributed most (22.1%), followed by smoking (15.4%), public insurance (9.8%), and BMI (4.9%). The direct effect was an aOR of 1.34 (95% CI, 1.12–1.61), explaining 47.7% of the total effect.

For NICU admission, the total effect was an aOR of 1.38 (95% CI, 1.17–1.62). The total mediated proportion was 38.5% (95% CI 29.8–47.2%), with inadequate prenatal care (18.2%), smoking (11.3%), insurance (6.4%), and BMI (2.6%) as contributors. The direct effect remained significant (aOR 1.23, 95% CI 1.04–1.45), accounting for 61.5% of the total effect.

Older adult mothers (>35 years vs. 19–35 years)

For preterm birth, the total effect of advanced age was an aOR of 2.94 (95% CI, 2.68–3.22). Five mediators were examined: pre-existing hypertension, pre-existing diabetes, ART use, pre-pregnancy BMI, and parity. The combined mediated proportion was 9.8% (95% CI 6.7–12.9%). Pre-existing hypertension contributed most (4.2%), followed by BMI (2.4%), pre-existing diabetes (1.8%), ART use (0.9%), and parity (0.5%). The direct effect was an aOR of 2.68 (95% CI, 2.44–2.94), explaining over 90% of the total effect.

For low birth weight, the total effect was aOR 1.95 (95% CI 1.74–2.18). The total mediated proportion was 28.6% (95% CI 21.3–35.9%). Pre-existing hypertension contributed 12.4%, followed by BMI (7.1%), pre-existing diabetes (5.3%), ART use (2.4%), and parity (1.4%). The direct effect was an aOR of 1.68 (95% CI, 1.49–1.89), explaining 71.4% of the total effect.

For NICU admission, the total effect was an aOR of 2.12 (95% CI, 1.92–2.34). The total mediated proportion was 31.2% (95% CI 23.7–38.7%), with pre-existing hypertension (13.8%), ART use (7.5%), BMI (5.2%), pre-existing

diabetes (3.2%), and parity (1.5%) as mediators. The direct effect was an aOR of 1.77 (95% CI, 1.57–1.99), accounting for 68.8% of the total effect.

Discussion

This comprehensive retrospective cohort study, involving 19,728 mother-neonate pairs over five years, offers strong evidence of a U-shaped pattern in pregnancy outcomes across different maternal age groups. Our analysis shows that both adolescent mothers (<19 years) and older mothers (>35 years) face significantly higher risks of adverse obstetric and neonatal outcomes compared to their young adult counterparts (19-35 years), even after controlling for key sociodemographic and clinical factors. Notably, adolescent mothers had considerably higher rates of preterm birth (aOR: 1.48), low birth weight (aOR: 1.72), and neonatal morbidity. In contrast, older mothers showed markedly increased risks of preeclampsia (aOR: 3.15), cesarean delivery (aOR: 1.89), and preterm birth (aOR: 2.94). These findings remained consistent despite thorough adjustment for potential confounders, supporting our main hypothesis that maternal age at both ends of the reproductive spectrum is associated with increased risk.

Our cohort's socioeconomic gradient warrants particular attention. Adolescent mothers exhibited significantly disadvantaged sociodemographic profiles, with higher rates of public insurance (85.2%), lower educational levels (94.9% with ≤ high school diploma), and notably inadequate prenatal

care (37.6%). In contrast, older mothers generally had higher socioeconomic status. However, they bore a greater burden of medical comorbidities, including chronic hypertension (5.8% vs. 0.8% in adolescents) and pre-gestational diabetes (3.1% vs. 0.5% in adolescents). These markedly different risk profiles highlight the complex interaction between biological and social determinants of health across the maternal age spectrum and emphasize the need for multidimensional approaches to risk assessment and patient care (Table 5).

Table 5. Summary of key adjusted associations between maternal age groups and primary outcomes

Outcome Measure	Adolescent Mothers (<19 years) aOR (95% CI)	Older Adult Mothers (>35 years) aOR (95% CI)
Preterm Birth	1.48 (1.25-1.75)	2.94 (2.68-3.22)
Low Birth Weight	1.72 (1.45-2.04)	1.95 (1.74-2.18)
Preeclampsia	1.12 (0.89-1.41)	3.15 (2.82-3.52)
Cesarean Delivery	0.65 (0.57-0.74)	1.89 (1.72-2.08)
NICU Admission	1.38 (1.17-1.62)	2.12 (1.92-2.34)
Composite Adverse Outcome	1.51 (1.31-1.74)	2.35 (2.14-2.58)

The neonatal outcomes observed in our study further reinforce this pattern of increased risk at the extremes of age. Infants born to adolescent mothers

showed significantly higher rates of being small for gestational age (aOR: 1.41), while neonates of older mothers faced greater risks of macrosomia and NICU admission. The composite adverse neonatal outcome, which includes perinatal mortality, severe respiratory distress syndrome, proven sepsis, or hypoxic-ischemic encephalopathy, was notably higher in both adolescent (aOR: 1.51) and older adult groups (aOR: 2.35) compared to the reference group of young adults. These findings collectively highlight a troubling situation where healthcare systems must support both the youngest and oldest mothers during the perinatal period.

The increased risk profile seen among adolescent mothers in our study aligns with the Biopsychosocial Model framework that guided our research. The notably higher rates of low birth weight (14.9% vs. 8.8% in young adults) and small-for-gestational-age infants (13.8% vs. 7.9%) among adolescents support the idea of maternal-fetal nutritional competition in biologically immature mothers. This phenomenon, where a growing adolescent and her developing fetus may compete for essential nutrients, offers a plausible biological explanation for restricted fetal growth [22]. Furthermore, the higher rate of anemia (30.7% compared to 18% in young adults) supports the idea of nutritional deficiency in this group, which may be exacerbated by increased iron needs due to ongoing maternal growth and pregnancy.

For older adult mothers, the significantly increased risk of preeclampsia (aOR: 3.15) and gestational diabetes (aOR: 2.87) reflects age-related

physiological changes that may negatively affect placental development and metabolic function. The aging vasculature has been hypothesized to exhibit decreased plasticity, which could hamper the normal process of spiral artery remodeling, essential for establishing adequate uteroplacental blood flow. This vascular dysfunction is a key factor in the development of preeclampsia and other hypertensive disorders, which were much more common in our older cohort [22]. Similarly, the gradual decline in pancreatic β-cell function and increasing insulin resistance with age likely contribute to the higher risk of gestational diabetes observed in this group [23].

Our findings strongly show that the risks linked to adolescent pregnancy go well beyond biological immaturity alone. The significant socioeconomic disparities observed in our adolescent group are key factors leading to negative outcomes, acting independently of and alongside biological factors. This complex interaction aligns with the framework proposed by the World Health Organization, which highlights how social determinants, such as limited educational and economic opportunities, can directly affect reproductive health outcomes [24]. The mediation analysis in our study statistically supported this conceptual model, showing that approximately 45% of the overall effect of young maternal age on preterm birth was mediated by socioeconomic status and the adequacy of prenatal care.

We acknowledge an important limitation of our mediation analysis: the residual 'direct effect' attributed to young maternal age (55% of the

adolescent preterm birth risk) almost certainly captures unmeasured psychosocial and nutritional variables rather than a purely biological effect of chronological age. Specifically, we lack direct measures of perceived stress (e.g., Perceived Stress Scale), social support (e.g., MOS-SSS), depression or anxiety (e.g., PHQ-9, GAD-7), or objective nutritional biomarkers (e.g., serum ferritin, zinc, folate, albumin). In clinical practice, screening adolescents for these factors with validated tools at the first prenatal visit could identify high-risk individuals for targeted interventions—such as referrals to mental health services, peer support programs, or consultations with registered dietitians. For older mothers, the >90% direct age effect likely reflects age-related biological processes, including decidual senescence, telomere attrition, mitochondrial dysfunction in placental trophoblasts, and chronic low-grade inflammation (inflammaging), none of which were directly measured. Clinically, this suggests that even optimal management of hypertension and diabetes may not fully normalize risk, and closer fetal surveillance (e.g., umbilical artery Doppler, placental growth factor testing) should be considered for women over 35 regardless of comorbidity status. Future prospective cohort studies should incorporate: (1) validated psychosocial instruments at multiple time points; (2) nutritional biomarkers (e.g., prealbumin, 25-hydroxyvitamin D, iron studies); (3) placental biomarkers (sFlt-1/PlGF ratio, placental growth hormone, cell-free fetal DNA methylation patterns); and (4) maternal inflammatory markers (hs-CRP, IL-6, TNF-α). Such data would allow formal causal mediation analysis with multiple

mediators and help distinguish true biological age effects from modifiable psychosocial and nutritional pathways.

To further elucidate the mechanisms underlying our findings, we conducted exploratory analyses of potential effect modifiers. For adolescent mothers, stratification by prenatal care adequacy revealed that the risk of preterm birth was substantially attenuated among those receiving 'Adequate Plus' care (aOR 1.18, 95% CI 0.95-1.47) compared to those with inadequate care (aOR 1.69, 95% CI 1.38-2.07), suggesting that intensive prenatal support may partially mitigate age-related risks. Conversely, for older mothers, the effect of advanced age on preeclampsia was magnified in the presence of chronic hypertension (interaction p=0.009), with aOR increasing from 2.89 (2.54-3.29) to 4.21 (3.56-4.98) among hypertensive women. Biologically, the near-complete mediation of adolescent risk by socioeconomic factors (45%) versus the predominantly direct effect of age in older mothers (>90%) supports distinct pathophysiological pathways: nutritional competition and uterine immaturity in adolescents versus placental aging, decidual senescence, and vascular dysfunction in older women. Clinically, these findings suggest that interventions targeting social support and nutrition may yield greater returns in adolescent populations, while stringent vascular and metabolic monitoring is paramount for older mothers.

The psychological aspect of the Biopsychosocial Model also needs careful consideration. Although it is more difficult to measure in a retrospective

study, the psychosocial stress linked to adolescent pregnancy—including potential lack of social support, increased anxiety, and delayed pregnancy recognition—might influence outcomes through neuroendocrine pathways [25]. Similarly, for older mothers, the complex interaction between age-related biological risks and the psychological stress of advanced maternal age pregnancy, sometimes following periods of infertility, may be an underrecognized factor contributing to the observed risk profile [14]. Future prospective studies incorporating validated measures of psychological stress would be invaluable in elucidating these relationships.

Several unexpected findings in our analysis warrant careful consideration. The lower rate of cesarean delivery among adolescents (38.1% vs. 60.2% in young adults) warrants careful interpretation. Our stratified analysis by indication revealed that this difference is largely explained by the high proportion of repeat cesarean deliveries among older groups (41-45% of cesareans were elective repeats), a pattern absent among primiparous adolescents. Among first-time, term, vertex labors, adolescents had significantly lower rates of cesarean for failure to progress (12.1% vs. 18.4% in young adults), despite similar rates for fetal distress. Possible explanations include: (1) younger uterine tissue may exhibit more efficient contractility and cervical remodeling; (2) lower fetal birth weight in adolescents (mean 2,980g vs. 3,240g in young adults) reduces mechanical dystocia; (3) lower rates of epidural analgesia (unmeasured in our dataset) may preserve second-stage pushing efficacy; or (4) provider bias—clinicians may be more willing

to attempt operative vaginal delivery or prolong labor in adolescents to avoid cesarean. The similar fetal distress rates suggest that provider bias, if present, does not extend to emergency indications. Future prospective studies should document labor management protocols and provider decision-making processes to clarify these mechanisms.

Additionally, the relatively similar rates of preeclampsia between adolescents and young adults in our cohort (7% vs. 8%) contrast with some previous literature [26, 27] and may reflect the protective effect of primiparity and overall lower prevalence of underlying metabolic risk factors in this population, despite their biological immaturity.

Our findings on the increased risks for teenage mothers closely match a growing amount of global research. A recent umbrella review of systematic reviews and meta-analyses involving 677,431 participants showed that teenage pregnancy was significantly linked to anemia (aOR: 1.49), stillbirth (aOR: 1.71), preeclampsia/eclampsia (aOR: 1.63), preterm birth (aOR: 1.90), and low birthweight (aOR: 1.46) [28]. The consistency between these pooled global estimates and our institution-specific data reinforces the validity of both datasets. It indicates that the risk profile of adolescent pregnancy may show strong consistency across different geographic and healthcare environments. Similarly, our findings on advanced maternal age align closely with research conducted in other populations. A recent South African cohort study examining the combined effects of maternal age and parity found that

mothers over 23 years old with at least one previous child had significantly higher BMI (28.6 kg/m^2) and a greater likelihood of hypertension (44.1%) and GDM (7.4%) [22]. The convergence of these findings and our observations strengthens the biological plausibility that age-related metabolic and vascular changes contribute to adverse pregnancy outcomes across different populations. The literature shows significant regional differences in adolescent pregnancy outcomes, providing important context for understanding our results. A recent study from Ethiopia reported much higher rates of adverse outcomes among adolescents compared to adults, including preterm labor (7.0% vs. 2.0%), antepartum hemorrhage (11.9% vs. 4.9%), anemia (19.3% vs. 10.2%), and pregnancy-induced hypertension (11.9% vs. 7.0%) [29]. The more pronounced risk difference in the Ethiopian group likely stems from broader socioeconomic disparities and reduced access to healthcare resources in this setting, emphasizing how social factors can affect the magnitude of age-related risks. Conversely, a large retrospective study from Turkey involving 16,985 women showed more varied results, with adolescent pregnancies linked to lower birth weight but similar rates of prematurity, preeclampsia, and stillbirth compared to adult pregnancies [30]. This difference from our findings and other studies may be due to variations in healthcare system organization, social support structures, or research methods. The Turkish study also showed lower cesarean delivery rates among teenagers (37.8% vs. 41.7% in adults), which

aligns with our observation and suggests this may be a common trend across settings (Table 6).

Table 6. Comparison of adolescent pregnancy outcomes across different geographic contexts

Outcome	Current Study	Ethiopian Study[30]	Turkish Study[31]	Umbrella Review[29]
Preterm Birth	15.9%	7.0% (preterm labor)	Similar to adults	aOR: 1.90
Anemia	30.7%	19.3%	Not reported	aOR: 1.49
Preeclampsia	7.0%	11.9%	Similar to adults	aOR: 1.63
Low Birth Weight	14.9%	Not reported	Higher than adults	aOR: 1.46
Cesarean Delivery	38.1%	16.0%	37.8%	Not reported

Our findings are further contextualized by recent studies from neighboring healthcare systems with similar demographic profiles. Golbasi et al. (2022) compared maternal and neonatal outcomes between Syrian adolescent refugees and local Turkish adolescents at a tertiary care hospital in İzmir, Turkey, a setting analogous to our own center [31]. Notably, Syrian refugee adolescents had higher rates of preterm birth ($p<0.001$), low birth weight ($p=0.014$), and anemia ($p<0.001$) compared to their Turkish counterparts, underscoring how socioeconomic vulnerability amplifies age-related risks beyond biological factors alone. In our Iranian cohort, adolescents also

showed markedly elevated rates of low birth weight (aOR 1.72) and anemia (30.7% vs. 18.0% in young adults), consistent with the Syrian refugee findings and further supporting the Biopsychosocial Model's emphasis on social determinants.

Bayraktar et al. (2021) examined adolescent twin pregnancies compared to adult twin pregnancies at a tertiary hospital in Turkey [32]. Although our study excluded multiple gestations by design (to avoid confounding), the twin study offers complementary insights: adolescent mothers of twins had significantly higher odds of moderate preterm birth (OR 2.34, 95% CI 1.34-4.09), low birth weight (OR 3.13, 95% CI 1.73-5.65), and NICU admission, with newborns weighing on average 191 g less than those of adult mothers. These effect sizes are notably larger than those observed in our singleton cohort (preterm birth aOR 1.48, LBW aOR 1.72), suggesting that the combination of adolescent age and multiple gestation carries synergistic risks. Collectively, these regional studies reinforce the generalizability of our core finding—that adolescent pregnancy confers excess perinatal risk across different Middle Eastern healthcare contexts—while highlighting specific vulnerable subgroups (refugees and twin gestations) that warrant targeted clinical attention.

Our analysis supports the findings of several studies showing that maternal age over 35 is a significant risk factor for adverse maternal and neonatal outcomes, including preeclampsia, gestational diabetes, cesarean delivery,

and preterm birth. Glick et al. (2021) noted that women of advanced maternal age face higher risks of complications such as spontaneous miscarriage, preterm labor, and chromosomal abnormalities [10]. These risks are similarly reflected in our results, where older mothers showed higher rates of cesarean sections and preterm births, especially for women aged 40 and above. Furthermore, the risk of hypertensive disorders during pregnancy, including preeclampsia, was consistently increased among women over 40 in our study. This aligns with findings by Lopian et al. (2023), who showed a strong link between advancing maternal age and hypertension [9]. Another notable observation in our results is the link between ART and higher pregnancy complications in older women, especially regarding preterm birth and low birth weight. This aligns with findings from studies like those by Frick et al. (2021), which pointed out that ART pregnancies, particularly in older women, carry greater risks of adverse outcomes such as preterm delivery and fetal growth restrictions [14]. However, we also found that ART did not significantly decrease the rate of adverse outcomes in women over 40, further supporting concerns raised by previous research about the limitations of ART in managing age-related reproductive risks. In line with previous studies [10, 19, 33-36], our findings reflect the increasing importance of managing comorbidities such as hypertension and diabetes in older mothers, as these conditions exacerbate pregnancy risks.

This study has several limitations. First, the retrospective design precludes causal inference; all associations should be interpreted as correlational.

Second, despite adjustment for multiple confounders, residual confounding is likely. Important unmeasured variables include ethnicity (predominantly Persian cohort), detailed socioeconomic factors (income, occupation, partner support), nutritional biomarkers, detailed substance use (alcohol, illicit drugs), maternal mental health, and interpregnancy interval. These unmeasured factors probably contribute to the “direct age effects” observed in our mediation analysis. Third, the single-center tertiary-care setting in Iran limits generalizability. Adolescent risks may be magnified in low-resource settings (where inadequate prenatal care is a dominant mediator) but attenuated in high-resource settings with comprehensive support. For older mothers, the predominantly direct effect of age suggests findings may be more transportable across settings. Fourth, we lacked biomarkers of placental function (e.g., sFlt-1/PlGF) or inflammation (e.g., IL-6) to test mechanistic pathways directly. Fifth, although we captured ART use, detailed subtype information (fresh vs. frozen embryo transfer, donor oocytes) was available only for a subset; our post-hoc interaction analyses for obesity, ART type, and prior preterm birth were exploratory and limited by sample size in some subgroups (e.g., donor oocyte recipients, n=178). Future large-scale, multi-center, prospective studies with biobanking and validated psychosocial instruments are needed to confirm and extend our findings.

Conclusion

In conclusion, our study provides compelling evidence for a U-shaped relationship between maternal age and adverse pregnancy outcomes, with both adolescent and advanced maternal age representing independent risk factors even after accounting for important sociodemographic and clinical confounders.

Declarations

- **Ethics approval and consent to participate:** The study protocol was approved by the Institutional Review Board and Ethics Committee of Kerman University of Medical Sciences (IR.KMU.REC.1404.471). Due to the retrospective and anonymized nature of the data analysis, the committee granted a waiver of individual patient consent. All data were de-identified before analysis, and the study was conducted in accordance with the ethical standards of the Declaration of Helsinki.
- **Consent for publication:** Not applicable. This manuscript contains no person's data (e.g., photographs, names, or identifiable details) that would require consent for publication.
- **Availability of data and materials:** Due to the sensitive nature of the clinical data and to protect patient confidentiality, the underlying dataset is not publicly available. De-identified data may be made available upon reasonable request to the corresponding author, subject to institutional review board approval and appropriate data use agreements.
- **Competing interests:** The authors declare that they have no competing interests.
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- **Authors' contributions:**
  - **Samaneh Movahedinia:** Conceptualization, methodology, investigation, writing – original draft, writing – review & editing.
  - **Najmeh Soltani Nejad:** Data curation, formal analysis, investigation, writing – review & editing.

- **Neda Nikpour:** Data curation, formal analysis, validation, writing – review & editing.
- **Maryam Mirzaei:** Methodology, investigation, supervision, writing – review & editing.
- **Samaneh Omidi Kermanshahaninezhad:** Conceptualization, methodology, project administration, supervision, writing – original draft, writing – review & editing, corresponding author.
- All authors read and approved the final manuscript.

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